Project Report
2009 TRRF05 *Fuel Cell Technology*
December 04, 2009, Lund, Sweden

Compare new designed flow channels of interconnect for planar SOFCs with typical channels

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ABSTRACT

Design of advanced flow channels in bipolar plates is one of the key factors affecting SOFC stack and system performance. Various transport phenomena occurring in SOFCs with conventional interconnects, such as rib-channels, serpentine channels, etc, have been extensively studied. In this paper new designed channels have been proposed and evaluated numerically by computational software.

The investigated geometry consists of two computational domains: a porous anode layer and interconnect, the latter one serves as gas distribution for hydrogen or air in SOFCs. Compared with conventional designs, the configuration of interconnect having honeycomb structures is different. Such unique channels lead to gas flow in many directions, and gas flow distribution and pressure drop are significantly different from those in previous studies. This simulation employs the Navier-Stokes equations for gas flow in channels, and the Darcy model in the porous layer. Combined gas and heat transfer in channels and the porous gas diffusion layer, permeation across the interface are analyzed by a fully three-dimensional code in this paper. All the governing equations are solved utilizing the commercial code COMSOL. The velocity field, the distribution of hydrogen in channels, the fraction of the hydrogen entering the anode diffusion layer, and the pressure drop are predicted and presented. Also, the numerical predictions of the cell performance are compared with the experimental results. The numerical results and findings from this study are important for optimizing the flow fields, decreasing the cost of experiments, designing the channels.

NOMENCLATURE *(OPTIONAL)*

R_e	Reynolds number
S	source term
T	temperature, K
U_i	velocity components in x, y and z directions, respectively, m/s

Greek Symbols

β	permeability of diffusion layer, m2
ε	porosity
μ	dynamic viscosity, kg/(m s)
ρ	density, kg/m3

Subscripts

eff	effective parameter
f	fluid
m	mass transfer

INTRODUCTION

It is known that the own characteristics of solid oxide fuel cell (SOFC) determines it has extensive application prospects in many areas. High efficiency of power generation, wide fuel for selectivity, zero emissions of sulfur oxides and noble metal catalysts not needed, etc are the benefits of SOFCs. The components of SOFC stack includes: anode, electrolyte, cathode and interconnect. Among these components, interconnect acts as a bipolar plate which electrically connects the anode of one cell to cathode of the adjacent cell, while also physically isolates fuel from oxidant and acts as a gas manifold to distribute reactant.

Uniform supply of gas species to the active surface where the electrochemical reaction happens is one of the key engineering problems in SOFCs. Advanced design of flow channels in bipolar plates which the geometry gas-flow configuration leads to uniform flow distribution and stable stack operation is significantly affecting SOFC stack and system performance. Moreover, understanding of various gas and heat transport processes is crucial for increasing power density, reducing manufacturing cost and accelerating commercialization of fuel cell systems [1]. Due to the highly operate temperature and compact nature of fuel cell stack, it is hard to detailed understanding transport phenomena in SOFC stack, also in interconnect. Consequently, modeling or simulation play an important role in optimize the configuration of interconnect and predict the performance of each cell. An appropriate design of fuel flow channel is beneficial to the reactant gas transport as well as the cell performance. In this paper, new designed channels have been studied and provided more choices to effectively improve the degree of flow uniformity in channels.

In this paper, a realistic interconnect is constructed and a multi-physics model coupling heat/mass transfer with constant current density is developed to simulate the transport phenomena in flow channels and permeation across interface between flow channels and porous anode layer. This will provide a complete basic for the gas flow distribution, pressure drop, velocity field, the fraction of the hydrogen entering the anode diffusion layer, etc. A fully three-dimensional COMSOL code will be employed to solve continuity, momentum and energy equations. Also, compared the numerical predictions of the cell performance with the experimental results is very important in order to understanding the transport progress and optimize the configuration. The purpose of the present work is to assist the designer to objectively observe the transport phenomena in this new designed interconnect with unique honeycomb-based channels. The new structural channel is helpful to develop various feasible choices for the design and establish certain guidelines to improve the flow uniformity, the effect of heat transfer and cell performance. More discussion of optimal size and electrochemical reaction will be reported in another paper.

PROBLEM STATEMENT

A planar SOFC stack is composed of repeating single fuel cells connected with interconnects in series. The unite cell consists of anode-channel, anode, electrolyte, cathode and cathode-channel. The map showed in Fig. 2.

Interconnect lead to homogeneous distribution of the feeding gases and accessible the zone of the electrode is greatly needed. Among different interconnect with various shapes channels, almost investigation on the channels are rectangular, trapezoidal. Compared with conventional designs, the configuration of interconnect having honeycomb structures is unique. Fig. 4 shows the partial channels. As the experimental test is expensive, time-consuming and difficult to explore the transport phenomena in channels, simulative approaches are favored in the design of channel-configuration. The calculations are based on multi-physics COMSOL. Because of symmetry, it is sufficient to model just a half of the entire geometry. The computational domains include both a porous anode layer and interconnect. For simplicity, a steady laminar flow of an incompressible fluid is considered and all thermal-physical properties are assumed constant. Flow is isothermal and laminar. Also the model is based on the assumption that the structure of the porous media is homogeneous so that the anode material can be described by three parameters, such as porosity, permeability and thermal conductivity.

The channels may be divided into two functional parts: supporting part which contact with electrode namely rib, gas-flow channel part. The rib and channel dimensions are shown in Table 1. For interconnect with particular channel, the geometric form is influential to the flow uniformity are to be: the shape, the height and length of the rib and channel, the pattern, location and size of inlet/outlet manifold and so on. In this paper, the main work is to analyze the novel geometry and the pattern of channels influence the uniformity and performance. The flow pattern classified by three kinds: co-flow, counter-flow and cross-flow. Schematics of them are illustrated in Fig.3 [11]. In this paper, it analyzes the co-flow.

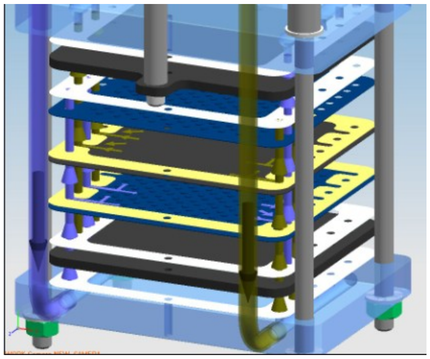


Fig.2 Schematics of SOFC stack.

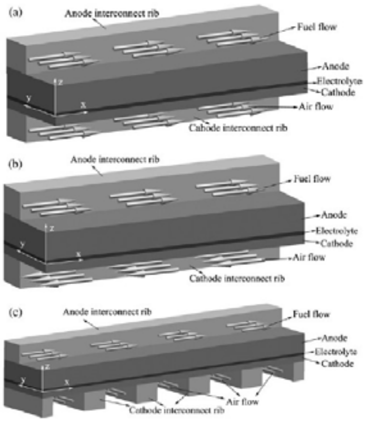


Fig.3 Schematics of flow-patterns: (a) co-flow; (b) counter-flow; (c) cross-flow.

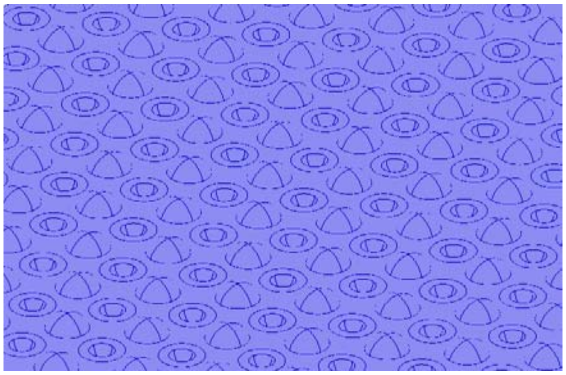


Fig. 4 Schematic drawing of the partial channels

Table 1 model dimensions

Parameters	Value
porous anode thickness(μm)	400
interconnect dimensions($mm \times mm \times mm$)	$100 \times 100 \times 0.4$
rib dimension(radius, mm)	1.25
flow channels(width, mm)	3.5

LITERATURE SURVEY

During recent years, lots of studies focusing on the gas and heat transfer within porous structure of SOFCs and many investigations concerning various type channels have been presented for simulation [11-16]. Hwang et al. [2] provided a study in the heat/mass transfer of fuel cell with a typical module of an interdigitated flow field plate. Detailed distribution of the local temperature, local Nusselt number, species concentration, and electric current density inside the porous electrode of fuel cells are presented.

Different designs of interconnects with different flow uniformity over a wide range of a hydraulic Reynolds number based on a hydraulic diameter of rib-channels have been investigated. It demonstrated that using simple small guide vanes equally spaced around the feed header of the double-inlet/single-outlet module improve the flow uniformity in interconnects resulting an increase of the peak power density [3].The drawing of the various interconnects showed in Fig. 1. Four different designs using the same 12 rectangular flow channels divided by eleven ribs, respectively, (Ⅰ)the single-inlet/single-outlet design, (Ⅱ)the double-inlet/single-outlet design, (Ⅲ)same as (Ⅱ) but with an extended rib in the center dividing symmetrically these 12 flow channels into two portions, and (Ⅳ)same as (Ⅱ) but with 10 small guide vanes equally spaced in the feeder region.

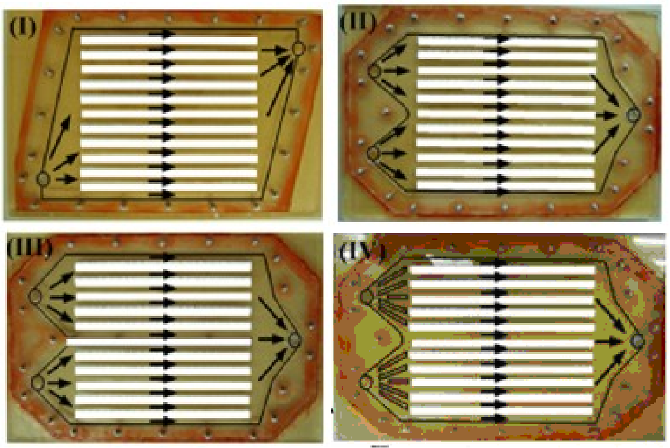


Fig. 1 Four different design of rib-channels modules for interconnects

Unique fuel cell boundary and interfacial conditions have been considered for gas and heat transfer in the porous support structure of an integrated-planar SOFC. The results revealed that the duct configuration and properties of the porous anode layer have significant effects on both gas flow and heat transfer of anode-supported SOFC ducts [1]. The model figure 2 is shown as follow:

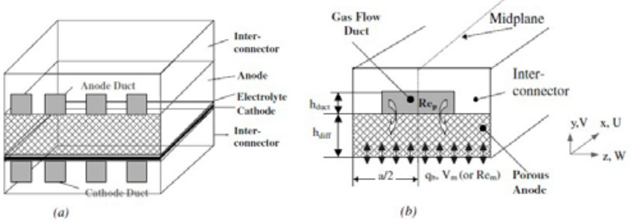


Fig.2 (a) Structure of a unit cell, (b) schematic drawing of a composite anode duct under investigation [1]

W. Tanner et al. [4] considered the proper design of interconnect in conjunction with single-cell is critical to minimizing the overall stack resistance. They analyzed two basic interconnect symmetries, one-dimensional (channels) and two-dimensional (dimples). The one-dimensional interconnect contacts of some width are periodically spaced at a distance, and their length extends across the entire cell. The two-dimensional interconnect contacts are circular in shape and are placed in a hexagonal array to cover the surface of the electrode. The main objective of this paper is to calculate the area-specific resistance per repeat unit consisting of a cell and interconnect for both interconnect designs. The area-specific resistance of one-dimensional symmetry was found to increase linearly as a function of the interconnect spacing while two-dimensional symmetry was increase parabolically. Thus, interconnects with widely spaced contacts of a small contact area should be avoided when an interconnect design when a two-dimensional is used. It was also found that the best design is the one having anode-supported cells with closely spaced interconnect contacts and a one-dimensional symmetry. Interconnect of one-dimensional and two- dimensional are presented in Fig. 3 and Fig. 4.

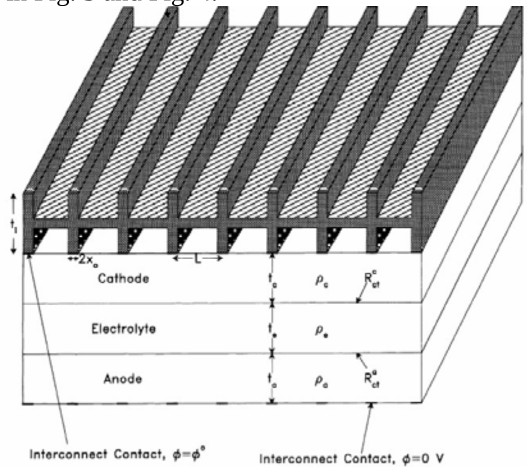


Fig. 3 A schematic of a SOFC in series contact with interconnect of one-dimensional geometry

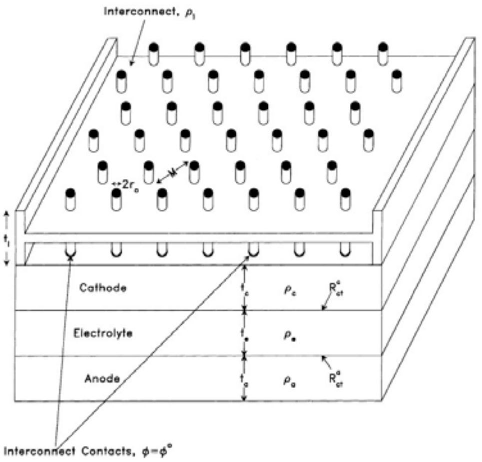


Fig. 4 A schematic of a SOFC in series contact with interconnect of a two-dimensional geometry

Valery A. Danilov and Moses O. Tade presented [5] a 3D CFD model of a planar SOFC with internal reforming for anode flow field design. Two designs have the same inlet and outlet manifolds. The new design is more uniform distribution of flow over channels. It includes new boundary conditions for charge balance with electrochemical reaction of hydrogen and carbon monoxide oxidation. Variation coefficients for velocity and temperature are used for the analysis of conventional and new anode flow field designs. The back-mixing in the inlet distributor of the conventional design significantly reduces the rates of chemical reactions and the fuel cell performance. Elimination of back-mixing and improvement in flow distribution in the new design provides better performance over the conventional design. The conventional and new flow field design show in Fig. 5.

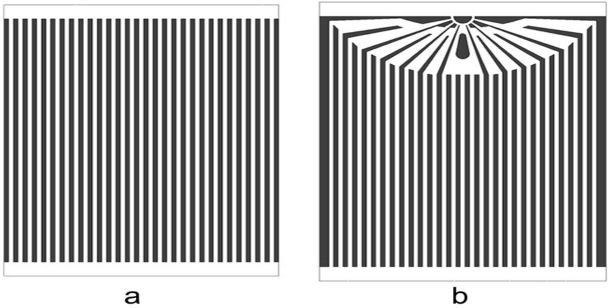


Fig. 5 Anode flow field designs. a) parallel flow field design; b) new flow field design

A typical flow channels included rectangular headers have developed to describe the problem of pressure drop and flow uniformity generalized in term of two non-dimensional variables, namely non-dimensional velocity, pressure and non-dimensional mass-flow rate. The results quantitatively analyze distribution changing with non-dimensional [6]. The configuration of interconnect presented in Fig. 6.

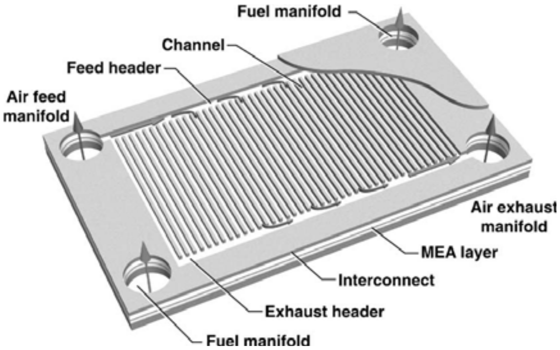
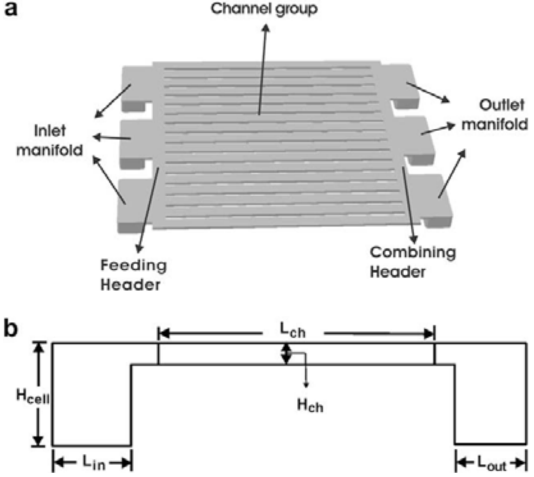


Fig. 6 Illustration of the flow field channels



The above Figure 7 shows a shape of interconnect. Bi, et al. [10] performed CFD calculations for the flow distribution in planar solid oxide fuel cell stack. The calculations are based on 3D models with realistic geometric and operational parameters. The effects of design parameters, such as the channel height and length, the height of the repeating cell unite and the manifold on the flow uniformity are examined. The results demonstrate that the ratio of the outlet manifold width to the inlet manifold with is a key design parameter that affects the flow uniformity.

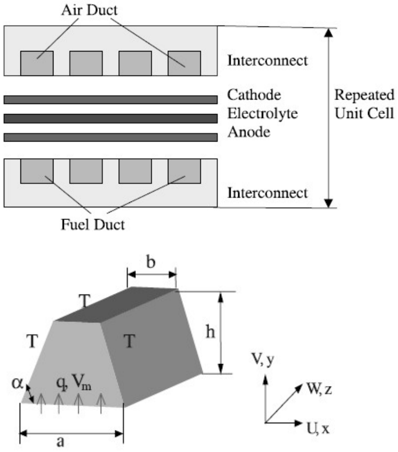


Fig. 7 schematic drawing of rectangular and trapezoidal ducts

Yuan, et al. [7] have simulated the flow in variously shaped channels, namely rectangular duct with different numbers of grid points and trapezoidal duct with different aspect ratios, base angles, wall Reynolds. They report both Ref values as well as Nusselt numbers for heat transfer analysis. Also, they have characterized the effects of mass transfer through the channel walls as happens in a fuel cell channel. The results reveals that the mass transfer through the channel walls has a relatively small influence on the value of Ref. The two shape ducts show in Fig. 7.

Lin, et al. [9] proposed that the gas transport in the porous electrode is treated by a phenomenological approach such that the gas concentration at the three-phase boundary (TPB) region is the additive superposition of that transport from the source, i.e. the gas channels. They estimated the effects of ribs on the concentration polarization of planar fuel cell operations. The studies shown that the model can closely reproduce the experimental concentration polarization curve for small and medium current density (up to about 2 A/cm2). They also discussed the concentration profiles with vary rib widths. The investigative results demonstrated: firstly, the rib width is small compared with that of the characteristic penetration distance, the gas concentration is uniform, secondly, the optimal rib design is expected to be between 1/3 and 2/3 of the channel width.

The pressure losses in the flow distributor plate of the fuel cell depend on the Reynolds number and geometric parameters of the small flow channels. Literature [17] reports a numerical simulation of laminar flow through single sharp and curved bends, 180° bends and serpentine channels of typical fuel cell configurations. The CFD-based calculations show that there's a significant effect of Re on the bend loss coefficient and the channel configuration is sufficiently affect the pressure drop. The following is the figure of different flow fields of bipolar plates.

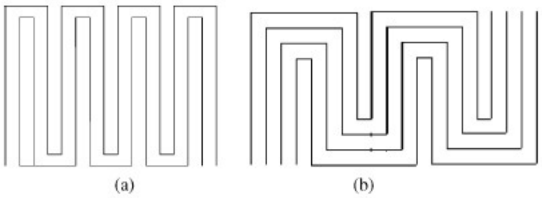


Fig.8 different flow fields of bipolar plates in planar fuel cells for: (a)serpentine channel; (b) parallel serpentine channel

A fully three-dimensional mathematical model for planar porous-electrode-supported (PES) SOFC has been constructed to simulate the steady electrochemical characteristics and multi-species/heat transport [14]. The governing equations of two types of new planar PES-SOFC are simulated by the finite volume method. For the cell using the same material and manufacturing process, the results show the type-Ⅱ PES-SOFC is with better performance. The schematic views of two types are shown in Fig. 9.

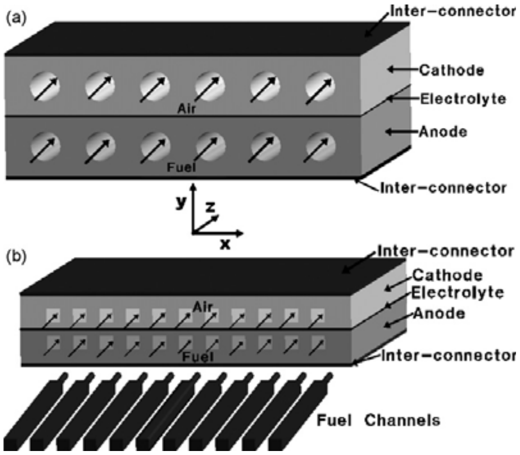


Fig. 9 Schematic view of two types of planar PES-SOFC: (a) type-Ⅰ and (b) type-Ⅱ

Generally speaking, almost all of the studies on the cell stack flow channels were based on typical configuration, such as rectangular, trapezoidal, cylindrical etc. In this paper, the configuration of channels is different from them, so the flow distribution and performance is also different. This kind of honeycomb-like constructer maybe is good in uniform supply of reactants and the heat transfer. Certainly, the size of the channel and rib need to optimize, and the performance will be much better.

PROJECT DESCRIPTION

The membrane-electrode assembly (MEA) layer is composed of an electrolyte that is sandwiched between electrodes. The electrodes are porous cermet materials that permit gases to be transported between the flow channels and the electrolyte surface. The interconnect supply reactants to active layer where electrochemical happens and output the production water. Also, the interconnect acts as a bipolar plate which electrically connects the anode of one cell to cathode. Uniform supply the reactant is significant important to the pressure drop, flow field, temperature, performance, stable and so on. Previously, lots pattern interconnects have been reported nothing but rectangular, trapezoidal, cylindrical etc. This study proposes a new design channel for choose to improve the uniform and performance and also can supply in heat exchanges. Fig. 10 illustrates the principal features of a planar SOFC architecture.

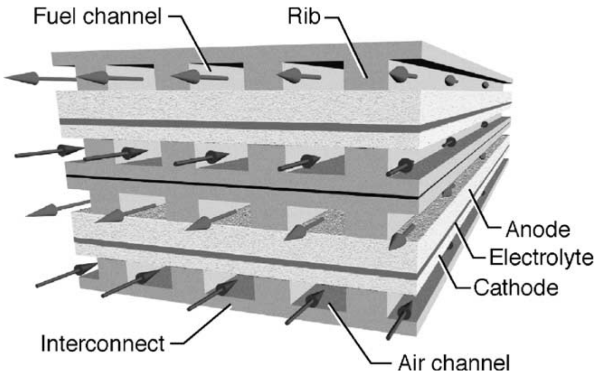


Fig.10 Illustration of a segment of two fuel-cell layers, including MEA, the interconnect, and the flow channels for fuel and air. A counter- flow situation is illustrated here, but co-flow and cross- flow configurations are also common.

GOVERNING EQUATIONS

The heat and mass transfer characteristics of gas flow channels can be modeled using conventional mass conservation, Navier-Stokes and energy equations. Gas flow as well as heat transfer in channels and permeation across interface between channels and anode porous layer are all presented. Part of the gas flow penetrates into the porous layer and the remaining gas flows down the channels. Neglect to consider the electrochemical reaction, the process are set several constant current densities instead. Consequently, it is simulated as a constant mass suction and injection at active surface where the electrochemical reaction happens. More simulation about electrochemical reaction and mass changing will be discussed in another paper. The governing equations are written as:

$$\frac{\partial\left(\rho_{\mathrm{eff}}U_i\right)}{\partial x_i}=S_m$$

$$\frac{\partial\left(\rho_{eff}U_jU_i\right)}{\partial x_j}=-\frac{\partial P}{\partial x_i}+\frac{\partial}{\partial x_j}\left(\mu_{eff}\left(\frac{\partial U_i}{\partial x_j}+\frac{\partial U_j}{\partial x_i}\right)\right)+S_{di}$$

$$\frac{\partial\left(\rho_{eff}U_jT\right)}{\partial x_j}=\frac{\partial}{\partial x_j}\left(\frac{k_{eff}}{c_{peff}}\frac{\partial T}{\partial x_j}\right)$$

All the subscript eff of the properties above mean effective values. The source term S_m in the mass conservation equation is a constant value which can be calculated by the assumed constant current density. The Navier-Stokes equation has been modified to be valid for both porous layer and the flow channels, by including a Darcy term S_{di} . It's comprehensively used in porous media.

$$S_{di}=-\mu_{eff}U_i/\beta$$

BOUNDARY CONDITIONS

Various types of interfacial conditions between a porous media and a fluid layer have been sufficiently studied. The boundary conditions of thermal and mass transfer used by Yuan [1] are employed in this paper. In addition, apply the interfacial conditions between the porous anode layer and flow channels supplied by literature [8]. In the current investigation, no-slip, velocity inlet boundary and pressure outlet boundary conditions are adopted for the simulation model. The velocity inlet is set as 1L/min and the operation pressure is 1bar. The half of interconnect is considered by imposing symmetry conditions on the mid-plane.

SOLUTIONS

The finite element commercial software COMSOL MULTIPHSICS is used in present study to solve the governing equations with the appropriate boundary settings. The half geometry for co-flow design is also complicated. There are 128 pairs of ribs and channels in the 10×5cm2 interconnect. The simulative results will be discussion in another paper.

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